

**THE REPUBLIC OF TURKEY
BAHCESEHIR UNIVERSITY**

**DEVELOPING VR SPORTS GAMES FOR DISABLED
PLAYERS: VR4INCLUSION CASE STUDY**

Master's Thesis

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ISTANBUL, 2021

**THE REPUBLIC OF TURKEY
BAHCESEHIR UNIVERSITY**

**GRADUATE SCHOOL OF SOCIAL SCIENCES
GAME DESIGN MASTER'S PROGRAM**

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Thesis Supervisor: ASSIST. PROF. DR. GÜVEN ÇATAK

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ACKNOWLEDGEMENT

I wish to express my deepest gratitude to my supervisor, Assist. Prof. Dr. Güven Çatak, who opened the gates of academics to me. I am always in his debt because he trusted me more than anyone and brought me forward on many international opportunities with his support, guidance and sincerity.

This study could not be executed without the guidance and leadership of my teacher, Assist. Prof. Dr. Mehmet İlker Berkman. I am grateful for his supervision in development and data collection besides his support during all testing events. I also would like to give my special thanks to my dear friend, Sena Semizođlu, who enlightened me in writing my thesis with her experiences.

The warm hospitality of The Spinal Cord Paralytics Association of Turkey during the dissemination events is appreciated.

Lastly, I would like to acknowledge the efforts of my mother and sister in supporting me.

Istanbul, 2021

Semih Bertuđ Benim

ABSTRACT

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July 2021, 64 Pages

With the developments in Virtual Reality and its diffusion in the market, individual players became able to use this technology at home. However, these devices have limited applications as they are primarily developed for individuals who do not suffer any disability. On the other hand, 15 per cent of the world population is disabled, and motivation plays a crucial role in their integrity and development. The lack of Inclusive Design techniques in Virtual Reality Systems causes empathy gaps. This project's primary aim is to explain design and development processes of Virtual Reality Sports games that both disabled and non-disabled individuals can play to fill this empathy gap. The study stands as a post mortem of three inclusive Virtual Reality Games developed under VR4Inclusion project which is an Erasmus+ project and funded by the National Agency. This work explains pitfalls and guidance to prevent the same mistakes in technical issues and research methods besides detailing the analysing process.

Keywords: Inclusion, Virtual Reality, Game Design, Disability, Inclusive Design

ÖZET

ENGELLİLER İÇİN VR SPOR OYUNLARI GELİŞTİRMEK: VR4INCLUSION SAHA ÇALIŞMASI

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Oyun Tasarımı Yüksek Lisans Programı

Tez Danışmanı: Dr. Öğr. Üyesi Güven Çatak

Ağustos 2021, 64 Sayfa

Sanal Gerçekliğin yaygınlaşmasıyla pek çok oyuncu bu teknolojiye evinden erişebilir oldu. Ancak bu cihazlar sınırlı sayıda ve ağırlıklı olarak engelsiz bireyler göz önünde bulundurularak geliştirilmekte olan uygulamalara sahip. Diğer yandan dünya nüfusunun yüzde 15'i engelli ve motivasyon, bireylerin topluma uyum sağlaması ve gelişimleri için çok önemli bir rol oynamakta. Kapsayıcı Tasarım tekniklerinin Sanal Gerçeklik sistemlerindeki eksikliği bir empati açığı oluşturmaktadır. Bu projenin temel hedefi engelli ve engelsiz bireyler için geliştirilen Sanal Gerçeklik spor oyunlarının tasarım ve geliştirme aşamalarını aktararak bu boşluğu doldurmaktır. Araştırma VR4Inclusion projesi kapsamında geliştirilen 3 spor oyununun analizi olarak yer almaktadır. Erasmus+ projesi kapsamında Ulusal Ajans tarafından finanse edilmiştir. Çalışma, araştırma yöntemleri ve teknik hataların önlenmesinin yanısıra, analiz sürecini detaylandırmaktadır.

Anahtar Kelimeler: Kapsayıcılık, Sanal Gerçeklik, Oyun Tasarımı, Engelli, Kapsayıcı Tasarım

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ABBREVIATIONS

APVG	: Activity Promoting Video Games
AI	: Artificial Intelligence
CP	: Cerebral Palsy
EE	: Energy Expenditure
HMD	: Head-Mounted Display
IOC	: International Olympic Committee
ISOD	: International Sports Organisation for the Disabled
SCI	: Spinal Cord Injury
VR	: Virtual Reality
WHO	: World Health Organization

1. INTRODUCTION

According to the World Health Organization (WHO), about 15 per cent of the world's population is disabled individuals. (PBS, n.d.) Every year, around the world, between 250,000 and 500,000 people suffer a Spinal Cord Injury (SCI). People with disabilities are at a heightened risk of social isolation. An estimated 20-30 per cent of people with spinal cord injury show clinically significant signs of depression. They bear the feeling of dysfunction and exclusion.

SCI can be treated with exercises to ease the pain and also make the motor functions work better. Making a couple of motions repeatedly without any short-term objective can be painful, exhausting and tedious progress. Also, each individual has a specific amount of energy to spend daily to maintain essential body functions. Energy Expenditure (EE) is a definition that refers to that amount and is determined by resting, metabolism and nutrition. (International Olympic Committee, n.d.) Unused energy expenditure can cause obesity, resting issues (CDC 2020). To add an objective, Activity Promoting Video Games (APVG) can help. One hour of APVG can increase daily energy expenditure by about 6-15 per cent (Van Naarden Braun et al., 2016).

Cerebral Palsy can be described by the Center for Disease Control and Prevention (CDC) briefly, as a group of disorders that affect a person's ability to move and maintain balance and posture and adds "the recent studies estimate that CP is ranging from 1 to 4 per 1,000 live births" (CDC 2020).

Unlike the other gaming platforms, the HMD (head-mounted display) based VR allows the players to move independently, without any limitations due to the screen's position. For this reason, it is a suitable platform for games that require physical activity. (Dillet 2018) Although it is relatively novel as a consumer product, Virtual Reality (VR) field is rapidly growing technology and is expected to reach 98.4 million sales by 2023. This means that VR will be a comprehensive technology and become feasible in a few years

for nearly everybody, yet it also means that the development in this area will be dramatic.

VR4Inclusion is an Erasmus+ project, realised with the partnership of Bahçeşehir University, International Spinal Cord Injury Association, Development and Innovation Office from Turkey, Trytaios Disabled Sports Club from Greece and Politechnica Slaska. The project includes the development of 3 Virtual Reality Games for both people with and without disabilities. It makes them compete against each other in the same competitive conditions while using the feedback from both sides and making them as reachable as possible. The project aims to create an opportunity for social interaction for physically disabled individuals through virtual reality technologies and gaming.

As an output of this project, boccia, hand-cycling (hand biking) and sledge hockey VR games were designed, implemented and evaluated by a group of disabled and non-disabled individuals. This thesis covers the project in two parts. First part is the case study and technical decisions of development. Second part covers the analysis of output where it has been explained by the participant feedback.

2. BACKGROUND AND RELATED WORKS

2.1 PARAPLEGIC GAMES

Modern Olympics are played in Athens for the first time, right after the founding of the International Olympic Committee (IOC). The Ancient Games of Olympia strongly inspire these games. In 1940 and 1944, the Olympics were cancelled due to World War 2. The first Olympic Games after World War II opened in London in 1948. The same day, in The Stoke-Mandeville Hospital, seeds of the Paralympic games seeds have been sowed. 60 Km away from London, Sir Ludwig Guttman introduced the first Stoke Mandeville Games for World War II veterans with spinal cord-related injuries.

Guttman's main intention was to prevent the pain of immobile bed rest for Spinal Cord Injury (SCI) patients. The first Stoke-Mandeville Games held on the grounds of a hospital featured 16 people competing in archery.

In 1960, the first official Paralympic Games, which also first took place in Rome, featured 400 athletes from 23 countries. Since then, they have taken place every four years. They competed in archery, basketball, swimming, fencing, javelin, shot put, club throwing, snooker, swimming, table tennis and the pentathlon. In 1964, the International Sports Organisation for the Disabled (ISOD) started offering opportunities for those athletes of visually impaired, amputees, persons with cerebral palsy and paraplegics. After 12 years, blind and amputee athletes competed in the Toronto 1976 Paralympics and athletes with cerebral palsy in Arnhem 1980. ISODs aim was to embrace all impairments in the future and to act as a Co-coordinating Committee.

“As adaptive sports grew, they attracted remarkable technical innovations. Early sports competitions featured wheelchairs weighing 50 pounds and more; athletes would chop

off pieces to streamline the chairs for competition. Today's chairs weigh 15 pounds and offer the athletes amazing opportunities for speed and manoeuvrability.”¹

2.2 SERIOUS GAMES

Serious games are defined as games used for purposes rather than entertainment, enjoyment, or fun. (Unity, n.d.) Nevertheless, “serious” more likely comes from delivering know-how or experience through its content (Laamarti et al., 2014); a successful serious game also uses “fun” in order to increase effectiveness. Mostly they promote learning by the motivation of achievement too.

By adding the engaging elements of video games to physical activities, or vice versa, physical

exercise seems to become more attractive (Michael & Chen, 2006). This is also known as Exergaming. It got its popularity after Nintendo Wii's release (2006) and the WiiFit component (2009) which makes it possible to do fitness through a game console. Just Dance (2009) allows players to dance in the real world and compete against their friends. The game also has a cardio mode. By this mode, players can do guided cardio while having fun. Wii's power in motion sense was also discovered by the hospitals. For CBS News, its popularity rapidly became regular in rehab therapy for those who are recovering from strokes, broken bones, surgery and even combat injuries in Herrin Hospital, Southern Illinois (2008).

2.2.1 Serious Games For Educational Purposes

Serious games allow learners to experience situations that are mostly impossible to practice often in the real world. They are also claimed to have positive impacts on the players' development of a number of different skills. (Susi T. et al.)

¹ About the Paralympics - <https://www.pbs.org/>

One of the first and vital examples of Serious Games is The Oregon Trails game developed for Apple II systems. (Minnesota Educational Computing Consortium, 1985) The game has the fun element and is rich enough to motivate people to learn about important historical events such as Louisiana Purchase and Westward Expansion.

Serious games have many purposes yet most of those games that can be called milestones are developed for Military and Training objectives. In 1980, Atari released a game called Battlezone which is a first-person shooter tank combat arcade game. The game uses green vector lines on black screen and represents one of the primitive 3D experiences. After one year of Battlezone release, the same game evolved into The Bradley Trainer which was developed for American Army to teach soldiers how to operate Bradley Tanks. (Laamarti F. et al.)

2.2.2 Serious Games For Disabled

As a related academic work, there are some boccia games in literature. First of them is a game called Boccia Virtual and developed by CRE Discapacidad y Dependencia in León, Spain. The game targets the paraplegic audience and can be played with WiiMote. The game has paralympic ramp mode and throwing mode. It is free to download and takes the role of a practice tool for paralympic boccia players.

One other work for the boccia game was developed under Universidade Técnica de Lisboa, Portugal. (CRE Discapacidad y Dependencia, 2018) As a downside, the game is only available to play with a keyboard and mouse or joystick.

The third Boccia game is developed under Polytechnic of Porto, Portugal. Boccia Simulator aims to make a serious game adapted for disabled individuals. (Ribeiro J.D., 2017) As a contradiction, the game is tested by an audience without disabilities. As the surveying method points, the study targets mainly realism rather than player accessibility.

Blinds must gather relevant spatial data on other sensory channels like hearing, haptic for orientating, route planning. (Loomis JM et al., 2001) Through those data, they should create “the spatial map” as detailed as possible. Blind-born individuals have an advantage since they get used to creating their spatial map without sight. For those who lost their sight in their later years, it is harder to train their dulled senses for orienting and route planning. “Audio-based Environment Simulator (AbES) is a novel, user-centered virtual environment that allows for simulated navigation and exploration of the layout of an existing physical building and set within an action video game metaphor” as Merabet LB. et al stated. (2012) They also have a hypothesis that “interacting with AbES would not only allow a blind user to generate an accurate spatial cognitive map of a target building, but also allow for the transfer of acquired spatial information to a large-scale, real-world indoor navigation task. ” The game has two different modes.

Gamer mode: Players navigate through a virtual environment using auditory cues to locate hidden jewels while avoiding chasing monsters.

Directed navigation mode: Players learn the spatial layout of the building and the relative location of the rooms with the help of predetermined paths and an assisting facilitator.

MathMelodies is another inclusive serious game that has been developed for iPads. Game aims to teach math to primary school students through sounds. Main reason for this design approach is to be accessible for students who have visual impairments. (Gerino A. et al., 2014)

2.3 VIRTUAL REALITY APPLICATIONS FOR SPORTS

Doing physical exercise on a regular basis is effective for motor skills improvement, yet using Mixed Reality can be more effective for most people (Khurana et al.). In Khurana’s study, there were 30 participants (28 males, 2 females) with traumatic spinal

cord injury on T6 and T12. They separated into two groups, and one group treated with real-world task-specific balance training while the other treated with Virtual Reality game-based training. Sony PlayStation 2 and EyeToy (Sony Computer Entertainment Inc., Beijing, China) were used. Birds and Balls, Soccer and Snowboard games played by the participants. At the end of the 4th week, mFRT, T-Shirt, and SCIM-III tests showed that the group who were given Mixed Reality game-based training had significant development of balance and functional performance in individuals with paraplegia compared to the group with real-world task-specific balance training in the test results.

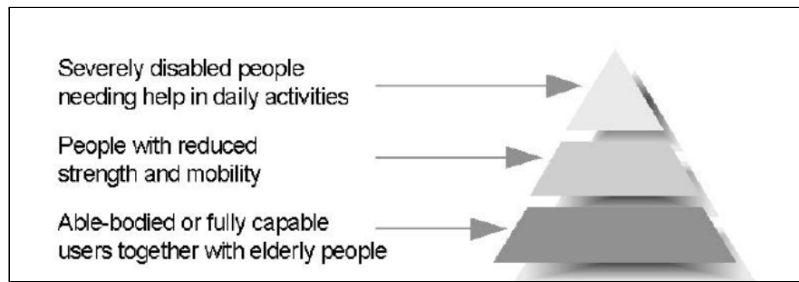
Codemodeon is a Turkish Company that expertising on VR experiences mainly for effective learning. They made Canoe, Mount Bike, Mini Golf and many others. Instead of using default HMDs that VR Technologies provide, they use their own gadgets. Canoe for instance, uses small 3DoF devices which attached to real paddles. Players try to pass a river while trying to collect as much as points in the shortest time as possible. It features scoreboard and multiplayer options.

2.4 INCLUSIVE DESIGN AND GAME ACCESSIBILITY

University of Cambridge states that every design decision includes or excludes some individuals from the product or service. (2017) Inclusive design focuses on maximizing the scope of the audience by understanding user diversities. This specific research area formed with the collaboration of designers, industry, educators and researchers (Clarkson P. et al. , 2003).

For Benktzon, during the development of new products, requirements and limitations of disabled users are important and added that inclusion of people from the higher level of the pyramid in the design process is necessary to reach a greater number of audience. Benktzon's inclusive design pyramid from elderly people to severely disabled people, creating a middle group consisting of individuals with reduced strength and mobility.

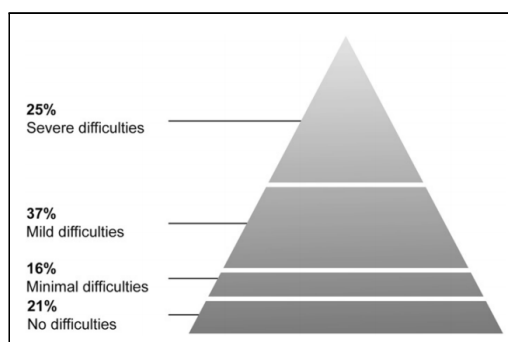
Figure 2.1: The modified Benktzon User Pyramid



Source: Demirbilek, O., 1999

As seen in Figure 2.2, segmented version of User Pyramid iterates this study as the pyramid is separated into four segments and names those as minimal, mild and severe difficulties with no difficulties. Percentages come from Microsoft's survey data (2003) of adults from the United States who are in working age (Waller S. Et Al., 2015). In both cases the top-down design approach for products can be reached to the largest audience. On the contrary, Inclusive design does not suggest that it is always possible to design one product to satisfy requirements of the entire population. Every design decision has potential to exclude customers while including others. However, developing products' derivatives provide the best possible coverage of the User Pyramid.

Figure 2.2: A segmented version of User Pyramid, 2013



Source: Waller S. et al., 2015

Inclusive Design and Game relation can be taken from two perspectives. First, games are used for teaching Inclusive Design and creating awareness. Second, applying this

method to designing inclusive games and reaching most of the audience by preventing any major disadvantages.

2.4.1. Games For Inclusive Design

As it has stated in the previous sections, Games are widely used tools for educational purposes. One of the examples of this is achieved by “Practicing Universal Design Principles in Design Education through a CAD-Based Game” - a.k.a. PUDCAD - which was developed by Bahcesehir University (Costa F. et al., 2019). Project mainly aims to train architecture and industrial design students about Universal Design and Ergonomics through a digital game. To realize this, the game combines several instructional methodologies (Catak G. & Toker C., 2020). During the game, players take the role of a person with mobility impairment, on a wheelchair. Non-inclusive objects such as coat hangers, a door etc. take the role of obstacles. Players enter the CAD-Mode, where they can adjust the position, scale and select an alternative of them, in order to complete objectives. To reinforce the teaching, some informative sketches appear at the corner of the screen.

2.4.2. Inclusive Design for Games

Game Designers and Developers mostly realize their games as the game that they would like to play. However, since those teams formed up from non-disabled gamers, this approach makes it harder to develop inclusive games. For Heron this points to both the problem and the solution (2012). Industry should consider hiring more disabled game developers for better game experience. By doing this, it also improves the quality of games for both disabled and non-disabled individuals in terms of accessibility. With the growing numbers of color-blindness, (Salih AE. et al., 2021) many game developers are suffering from that. This increased awareness and caused the addition of colorblindness mode in games such as Sea of Thieves (2018) and League of Legends (2009).

Blindness is a major blank point of the industry since games mostly focus on visuals. For blind people, audial games are an easy and interactive method of learning while taking the role as a source of entertainment. (Balan O. et al., 2015) As the work describes, “To be accessible and appealing to visually impaired people, audio games should fulfill the following specifications.”

- Immersion and attractiveness: to motivate the user to advance in the game. Diversity in audio clues.
- Lower difficulty: Rare “game over” situations to encourage players continuing to play.
- Clarity: A single and clear way of resolving the issues raised by the scenario.
- Intuitive learning strategy: Players should understand the requirements without the use of human or text-to-speech instructions.
- Interactivity, engagement and fun: Players benefit from an enjoyable and entertaining experience.

Shades of Doom (2005) is a successful example about achieving those criteria. It is a FPS game for blinds. The game uses dynamic and realistic multi-layered, 3D sound with up to 32 sounds playing simultaneously which can make use of a stereo or surround sound system. To aim in this FPS game, players should listen to beep noise. As the aim gets correct, the sound of beep increases. Because the game localization is harder than changing the texts only, a major downfall of this and similar games is the language barrier. Language is not the only barrier; players without blindness demand realistic graphics and most of them do not want to play games without any graphics at all. This may count as a good example for integration but not for inclusion.

Deaf players have better options in terms of inclusion. Subtitles in cut-scenes and dialogues are common. Gunshot sound may require immediate sign that their character is being fired upon. Closed-captions are available for many games which enables this gunshot and similar feedback to players. However audio channels also provide players the direction of sound source according to the player.

Good UI and UX design should give information not only restricted to a single channel of sensory input, but also incorporate visual or haptic feedback along with game events. Some successful games give this feedback successfully. The Call of Duty franchise (2003) gives players the direction of damage by tinting the specific edge of the screen.

3. DATA AND METHOD

This study aims to emphasise the importance of inclusion on VR Games while adding three new game alternatives to encourage disabled individuals. This section covers the detailed progress about the games' choice and design from the developer's perspective.

As materials, three games have been designed and developed on mobile Virtual Reality devices. The main challenge was making the game accessible for individuals with disabilities and making the win chance even with those who don't suffer from any disability. After each development iteration, play-test events are held. During those events, some surveys applied to the players.

3.1 DESIGN DECISIONS

3.1.1 Content Decisions: Determining the Sport

During the project, a player-centred approach is followed. The contents of the games are determined regarding the outcomes of meetings with three focus groups. These focus groups formed out of young disabled participants. The first group included 9 participants aged 14 to 23 and the second group included 8 participants aged 15 to 18. Groups are formed from students of a special educational institution in Athens. The last group of 9 participants were para-athletes, aged 23 to 54. Their physical disabilities vary, as some had paraplegia, some had quadriplegia while some have major motor dysfunctions.

In the first part of the focus group sessions, participants were asked to explain about their disability, daily activities, use of a wheelchair if they do, their involvement in sports, digital media use and gaming, prior VR experiences and expectations of VR in terms of realism and physical activity. Later, they were exposed to sport-themed games, skiing, basketball, ping pong and archery games on either Oculus Go or Gear VR.

In the second part of the session, they were asked to discuss their likelihood to own a VR system, does it match their prior expectations, what they experienced so far and the qualifications of their experience such as ease of use, challenge, interactivity and realism. The experience of physical activity in terms of appropriateness of the level of exercise for disabled people, disabled athletes and non-disabled people are learned. Finally, the participants were queried on their knowledge of adaptive sports for disabled people, followed by a discussion on the content of the games.

Most of the younger students of the test group have been born with a disability, while the majority of the older group were injured in an accident. The younger students are involved in sports because they are encouraged by the others, while most of the athletes were already involved in sports before they got disabled.

Some of the wheelchair users use it at home during dining, resting and watching TV, and others prefer canes and other alternatives. Caregivers usually help the younger patients move around while they are at home instead of using wheelchairs or other aids. They exercise at home, using dumbbells or a particular set-up of ropes. They also get help from physiotherapists regularly.

Boccia is a popular sports activity amongst most young students and all of the athletes and is practised regularly. Other sports activities mentioned were swimming, ping pong, taekwondo, javelin throw and chess. In addition, one of the participants tried mono-ski, while many declared that they are interested in javelin throwing and swimming.

In line with their experiences, they anticipated seeing a boccia game on a VR Platform. Swimming and skiing were other popular answers as a VR experience, followed by Table Tennis. Basketball and volleyball are frequently mentioned, and some water sports such as rowing, surfing, canoe and kayak, cycling, curling, and archery are mentioned.

Participants' digital habits are similar to their non-disabled peers, as they all own mobile devices. Youngs play games on mobile, tablets, computer and engage with social media. Male participants are more likely to play on computers and consoles, while females prefer mobile games. Being likely to own VR, its price is an important fact. Elderly disabled athletes play fewer digital games compared to young students. They state they have prior knowledge of VR but never tried it before.

They describe VR as "Great" - a vague definition by younger students, "Like living it", "7.5 over ten realistic", "like a dream - than come back to reality", "like to live the experience by doing things I couldn't do in real life", "what you see will be something moving but not real".

After experiencing VR, they were asked again about their likelihood to own a mobile VR system. One of the participants, who already own a Playstation VR, stated that he would not own a mobile one. This affected others for their likelihood to own a mobile VR headset.

Group 2 and 3 participants were likely to own while stating their concerns on cost. During the VR experience, some participants show mild cybersickness symptoms. In addition, the controls, which especially require sharp head movements, were reported to be unsuitable. Also, some participants experienced difficulties reaching the control buttons on the side of the Gear VR headset, which shows a handheld controller of Oculus Go is more suitable for them.

The last part of the discussion was about finalising the content of the games. The younger participants claimed that VR could be an opportunity for them to try out the sports activities they cannot perform in the real world due to physical limitations. They were not attracted by the idea of a paralympic sport on VR other than boccia, such as hand-cycling or curling. The moderator affected the bias by reminding them that VR sports games on the marketplace are not adaptive. As they agreed with the idea of

having an adaptive sports game for VR, they stated their want of trying sports for non-disabled people as a VR game.

On the contrary, the disabled athletes were highly supporting the idea of having adaptive sports on VR platforms, as it would increase the awareness of these sports among both disabled and non-disabled people.

Due to its popularity among the test group, boccia was the most demanded option as a VR game based on “ease of access” according to the simplicity of the equipment. It is followed by team sports such as wheelchair basketball, curling and ice hockey. Even the participants did not remark on hand-cycling; they did not refuse it when suggested.

Evaluating the focus group results and technical limitations, games for VR to develop, decided by followings:

- i. Boccia game
- ii. Hand-cycling
- iii. Sledge hockey.

The main reason for choosing the boccia game was its popularity among the audience. Although it is a competition team game, it is less complicated to implement the rules, can be played against AI and does not require sudden moves that may lead to cybersickness, compared to other competition ball games such as basketball.

The sledge hockey is selected based on suggestions by participants. Since it requires team play, it requires extended development and more budget to implement multiplayer option or AI team members and opponents. The game decided to be a skating and shooting practice due to those limitations.

Hand-cycling is selected since it offers continuous physical activity through a motion controller.

3.1.2 Technical Decisions: Determining the Platform

Unity3D is a game development focused, 3D development environment that also supports Extended Reality solutions.(Grubb, 2016)(Khurana, 2017) Besides that, there is a vast repository of programming and visual components that can be used when developing applications using Unity, namely Unity Asset Store, along with rich documentation and excellent community support. Therefore it is decided to be the primary tool to develop games.

One of the key objectives was making the game as affordable and reachable as possible by the target audience. Therefore, many up-to-date virtual reality systems have been examined. After this examination, it is determined that Mobile VR devices will be a better choice. To increase Virtual Reality impact and make the interaction more believable, those devices narrowed down to devices with at least 3DoF support.





3.2 DEGREES OF FREEDOM

Degrees of freedom (DoF) refers to the number of fundamental ways a rigid object can move through 3D space. There are six total degrees of freedom. Three of them refer to rotational movement around the x, y, z axes, while the other three refer to translational movement, which is also known as moving up, down, left, right, forward and backwards.² It is commonly used for headset devices and controllers and described as 3DoF and 6DoF. However, because of the cost and a requirement for extra peace of tracker, not all VR Devices have that 6DoF Technology. Therefore 3DoF devices are common and affordable.

There were four state-of-the-art platforms available for our games. They are briefly described in Table 3.1.

² Acquired from <https://developers.google.com/vr/discover/degrees-of-freedom>

Table 3.1: Mobile VR devices

Cardboard	Google's easy to use, highly compatible semi-VR solution. It works with almost any smartphone, but the interaction is limited to the head movements, touchscreen, and the magnetometer on the mobile device.	
Daydream	Google-specific VR solution. It supports a pair of 3DoF Controllers that enables users to interact with both hands but compatible with a limited number of mobile phone models.	
Gear VR	A mobile VR system that runs on several Samsung mobile phones. It supports 3DoF controllers, and it is compatible with the applications developed for Oculus Go.	
Oculus Go	A standalone HMD display that includes an Android mini-computer and a 3DoF controller. As a result, no cell phone is required, and device compatibility issues are less problematic.	

Mobile Virtual Reality devices have limited technological capabilities - low memories, lack of cooling systems etc. That limits the calculations and graphical realism. Since the polygon amount affects the game performances, low poly, ready-made assets have been used.

3.3 DEVELOPMENT AND IMPLEMENTATION

Boccia game was selected as a pilot project of 3 games and the first game to implement amongst them because of the great interest in the focus group. For development, task priorities are decided as follows.

- i. Determine required assets
- ii. Device and Development Tools adjustments
- iii. Create the scene with those assets
- iv. Learn official rules of Boccia Game
- v. Implement rules
- vi. Implement controls

As a design choice, assets are selected with the same style for all three games. Chosen models have low polygon count and vibrant colours. Since the internet does not have much choice for paralympic tools -such as handcycle, boccia ramp etc.- those specific tools modelled in Blender. They are modelled with the same style and low poly count.

Figure 3.1: Used environment asset pack



Source: POLYGON Town Pack - Low Poly 3D Unity Asset Store Webpage

Figure 3.2: Ramp, handcycle and sledge hockey models



3.3.1 First Trials with Google Cardboard

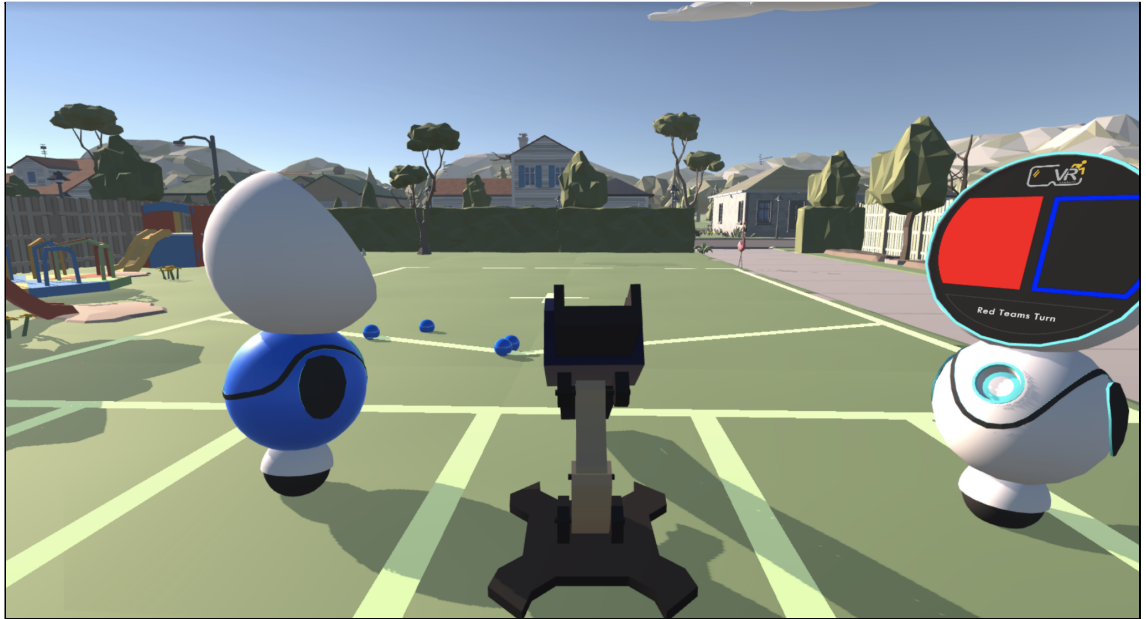
Google Cardboard is considerably affordable yet does not support any motion controller. On the other hand, this limitation directs the design process by taking the Paralympic Boccia game as an example.

In Paralympic Boccia, players have a ramp that a helper directs. The player guides the helper with gestures to rotate and position the ramp properly. Afterwards, the player has to push or release the ball from the top of the ramp. In this digital implementation, the control scheme is designed using only Head Movement in the following order. The game progresses through these 3 steps;

- i. Horizontal Head Movement to adjust the angle towards the game area.
- ii. Vertical Head Movement to adjust the steepness of the ramp.
- iii. Shoot.

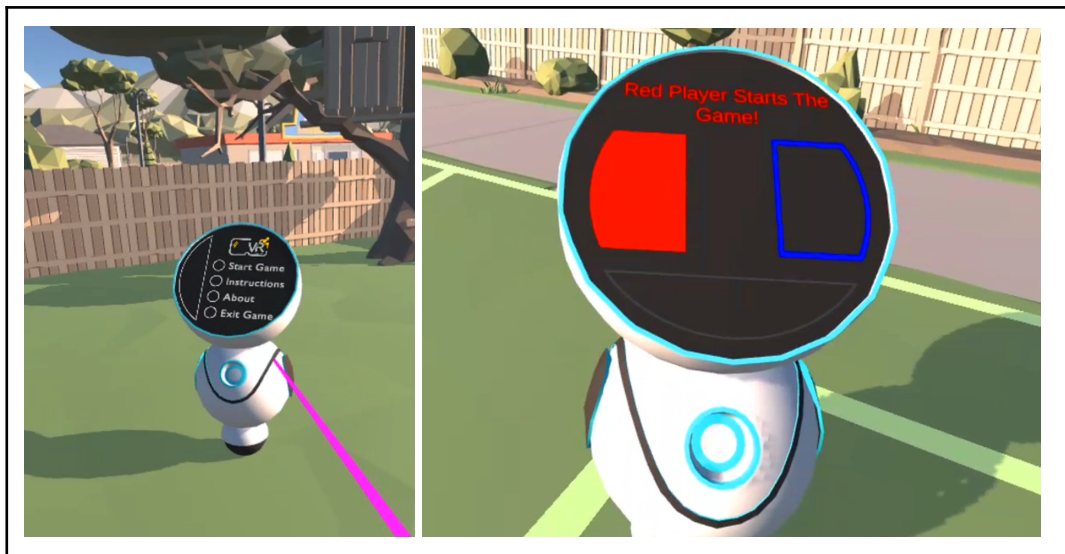
In order to continue, player needs to press a button. Since each controller input datas may vary, the game uses any button input which can be achieved by the “Input.anyKey” code in Unity.

Figure 3.3: Boccia scene view



Player tests show that this “mimic” approach works for good enough. However, one flaw of this approach is telling of the current phase and game rules to a new player. In order to give that information to the player, a robot helper modelled. The robot’s face shows all the information, menu choices and instructions with text and images.

Figure 3.4: Robot helper for the game.



After rough prototyping of Boccia, Hand-cycle has been implemented. For consistency, the same map has been used by slightly adjusting for the course. Due to control limitation, the game can be played by leaning to rotate and press a button to toggle between speed and brake.

In real life, Sledge Hockey - also known as Sled Hockey or Para Ice Hockey - has the same rules as regular Ice Hockey. The main differences are the equipment they use. Players sit on a particular design sled with two blades. Each player also has a pair of sticks. While the stick looks like regular hockey sticks, it also has metal pics on the butt end and is shorter than them. Those pics help players to gain momentum. (USA Hockey, n.d.)

As described in the design choice section, the limitations shaped the design as move and shoot practice. On this occasion, button swap the stick functionality for move and shoot. The main objective is shooting the puck into the keep while a robot goalkeeper constantly patrols in front of the keep may obstruct. The Player got five tries for the total. For the level design, a smaller, open ice skating area added to the same environment as Boccia and Hand-cycle.

3.3.2 Iterating Project into Daydream and Oculus VR Technologies

Daydream is a device that only works with specific phones, mostly from the Samsung brand. Daydream also has a 3DoF motion controller, both original and imitation options. Since specific test devices were hard to find, development continued with emulations and jailbreak devices. After unsatisfying results from this method and as Unity3D uses the same framework with Oculus GO, development continued with the latter.

Oculus Go is a standalone device, and it is one of the most accessible options for development. To start implementation of the Oculus version, Cardboard Scene -that has been developed- built for Oculus Go too. The second challenge was implementing

motion control. The tricky part was while the throwing motion in real life requires six dimension movement of arms. Since Oculus Go and Daydream got 3DoF controllers, it needs to be simulated and feels correct as possible.

For throwing a boccia ball, the human arm draws an arc and then releases. At the release moment, the arm passes all the momentum to the ball. This momentum can be crudely simplified by the angular velocity of the arm at the release moment.

Figure 3.5: The math of Angular Velocity

$$d\omega = \frac{d\phi}{dt}$$

Since 3DoF devices can not calculate linear movement, $d\omega$ can be calculated by the angle difference between the frame that the player releases the trigger button and the frame before. The time difference between two frames ($d\phi$) can be obtained by Unity3D's *Time.deltaTime* function. (Unity Technologies, n.d.) To prevent accidental trigger presses, it requires a press time of more than a second.

Hand-cycle handle works as an acceleration tool just like regular bike pedals. It also controls the steering of the bike at the same time. 3DoF Motion Controllers can not detect leaning or rotational movement. Leaning motion assigned to HMD Device. Due to rotation limitations, the Motion Controller's movement speed is taken for setting the velocity. As long as the player moves the controller, the angle, movement direction is ignored. This approach also helps to improve the player with higher disability experience since they struggle with large cycle motion. Controller speed calculated by angle difference($d\phi$) between two frames and multiplied by the *deltaTime* value.

Same acceleration method applied to Sledge Hockey game. The puck also follows the player to make control easier. As the player holds the trigger value, it switches to the shooting phase. As the player swings the controller and releases the trigger button, the forward vector at the release frame is stored. This vector applied to the puck as a force.

3.4 GATHERING PLAYER DATA

3.4.1 First Playtest Session and Iteration

On 25 December 2019, Boccia and Handcycle games met with the audience at the Istanbul Dissemination Summit. Event supported by Turkey's National Agency under the name of "Physical and Social Inclusion of Paraplegic Youth by Using Virtual Reality Project" and held for one week.

As a part of this event, disabled and non-disabled young people collaborate in some physical and creative activities. Participants are formed from the Development and Innovation Office, International Spinal Cord Injury Association from Turkey, Tyrtaios Disabled Sports Club from Greece and Silesian University of Technology from Poland. They tested both VR applications for this week. However Sledge Hockey was in its early alpha phase until this event; therefore, the audience did not prefer to try it.

Figure 3.6: Picture from the first dissemination event in Istanbul



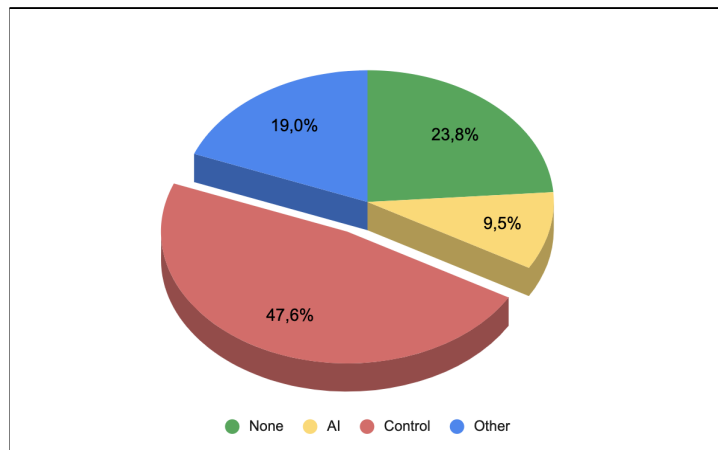
On the last day of the event, three mixed teams formed from participants with and without disabilities. Each team member plays the Boccia game against AI. Their scores are stored in an excel table. The addition of team member scores decided the team

score. The team with the highest score won the tournament. The aim was to test the inclusion factor of the Boccia game. Results showed that disability does not have any correlation with personal scores.

Table 3.2: Scores with disabilities.

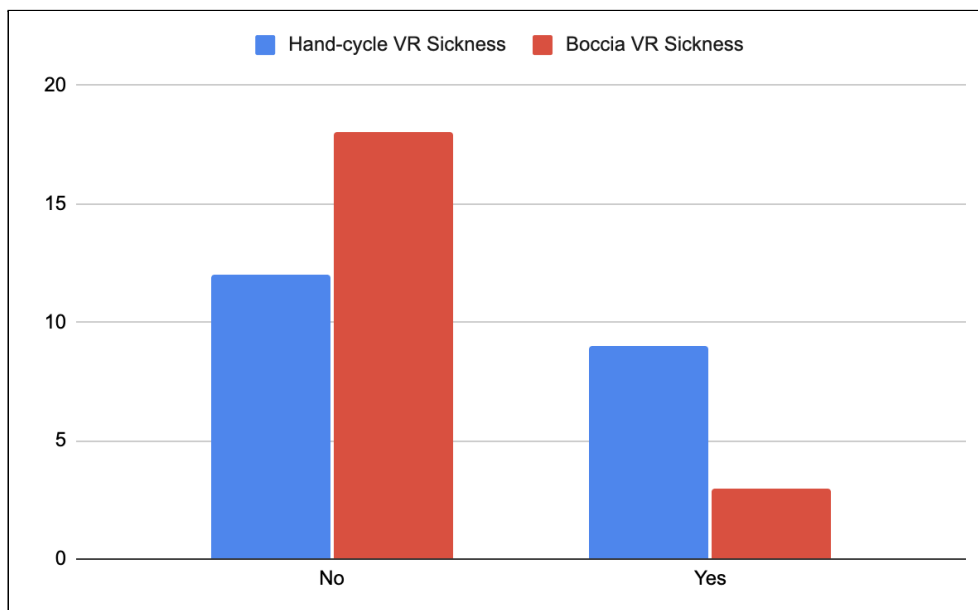
Team 1		Team 2		Team 3	
Player	Score	Player	Score	Player	Score
Şahin	0	Barış	2	Büşra	4
Seren	0	Mustafa	0	Mesut	0
Dimitri	0	Klaudia	4	Nihat	3
Burcu	3	Hannah	4	Sergei	0
Sinem	3	Özge	0	Beyza	1
Kostas	1	Samet	4	Furkan	4
İbrahim	5	Tugay	3	Ümit	0
TOTAL	12	TOTAL	17	TOTAL	12

Figure 3.7: Graphics of negative thoughts about Boccia game



After the tournament, they have been asked to participate in a surveying session about the games they have played. Boccia survey results point out that the controllers have issues about not being informative and have good feelings.

Figure 3.8: Graphics of VR sickness in Hand-cycle and Boccia Games



Cybersickness is a common issue in Virtual Reality and shows similar symptoms of Motion-Sickness in patients. People who have Cybersickness mostly suffer from Eyestrain, Headache, Pallor, Sweating, Dryness of mouth, Fullness of stomach (LaViola, 2000). In the survey, 14 per cent of players stated that they suffer from Cybersickness during their play session of Boccia. This amount increased to 42 per cent in Hand-Cycle. This might be caused by the decisive self-motion feeling by the visual illusion, which is also known as Vection (Dichgans & Brandt, 1978).

During the AdHoc survey, they stated that mixed team construction and competition between disabled and non-disabled participants increased their morale and encouraged them.

3.4.2 Second Meeting and Survey Results After Iteration

On 18 January 2020, the second dissemination activity of the project occurred. Event held in Turkey Spinal Cord Paralytics Association, Ankara. The panel with training participants and participants from the first event have been held. They answered the questions about the inclusive games and the games they have played.

Figure 3.9: The panel during the Turkey Spinal Cord Paralytics Association event.



During the event, Boccia, Hand-cycle and Sledge Hockey games are played. Games were already improved with the feedback acquired from the event before. Boccia rules and major bugs were fixed besides throwing power adjustments. To increase the spatial presence, the ball became possible to be grabbed and moved around before throw. The AI they compete with and graphics quality is improved. In the first event, users

Cardboard versions of the games were released in Google Play. Participants were informed about acquiring published games to their mobile devices. To improve the reachability, free Google Cardboard sets are given to all participants.

At the end of the Ankara Event, more comprehensive surveys were applied. This survey aims to learn their background with Virtual Reality, presence and pleasure measurement for the project games and accessibility and detailed in chapter 4. Game developments continued by the feedback acquired in Ankara. Publishing in the Oculus Store was the primary aim to satisfy “reachability“ criteria.

4. FINDINGS

4.1 EVALUATION OF PLAYERS FEEDBACK

To measure outcome games' feats, players participated in rather long survey sessions. It is important to mention that those surveys are based on only the Oculus Go version of games. Since the cardboard versions of those games have no additional controller, they are excluded from this survey. The survey is formed up by the following sections:

- i. Generic information of participants: This section is formed to gain demographic information of play-testers.
- ii. Multiple-Choice Section: This section aims to gain information about play-testers knowledge about targeted paralympic sports.
- iii. GUESS: Game User Experience Satisfaction Scale is a tool for measuring video game satisfaction (Phan et al., 2016). It uses the 7-point, unipolar scaling system in the level of agreement (Vagias 2006). Original survey uses nine measurement factors, which are Usability/Playability, Narratives, Play Engrossment, Enjoyment, Creative Freedom, Audio Aesthetics, Personal Gratification, Social Connectivity, and Visual Aesthetics. However, in the scope of this thesis, Usability/Playability and Enjoyment factors are selected.
- iv. Pictorial Presence SAM: This test formed is to measure Spatial Presence considering 6 pictorial items: attention allocation, spatial situation model, self-location, possible actions, cognitive involvement, and suspension of disbelief dimensions. (Weibel et al., 2015)
- v. AdHoc Questionnaire: To learn about likes and dislikes, accessibility, downsides and struggles of the testers.

Survey results show that 52 per cent of the participants have a disability whose disability rating ranges from 64 per cent to 96 per cent. The average disability rating is 77.6 per cent amongst the disabled players. Most of the testers have orthopedic disabilities. Testers mostly had 1 to 5 hours of experience on VR before the event. Most

participants also spend 1 to 5 hours playing mobile games daily. They either heard or watched those games before; however, most of them did not experience it firsthand.

SAM test results indicate 6 aspects of games. For Attention, lower numbers show greater attention. However for other values, higher scores indicate higher Spatial Presence, Cognitive Involvement and Believability. On the other hand, SAM misinterpretations should be considered. Misinterpretation ratio is the highest on Attention and Disbelief criteria by 16.6 percent (Weibel D. et al., 2015).

Surveys are applied to the players who play those games and there is not any affection during their preferences. The number of the players (n) also may indicate the preferences of the games. Since the least player pool is in Sledge Hockey, the player base doesn't prefer complicated VR games.

Table 4.1: SAM results

	Boccia (n=16)			Handcycle (n=14)			Sledge Hockey (n=7)		
	Avg	Mode	Std. Dev	Avg	Mode	Std. Dev	Avg	Mode	Std. Dev
Attention Allocation	1,938	1	1,289	1,929	1	1,207	2,143	1	1,464
Spatial Situation Model	2,938	3	1,482	3,643	4	0,842	3,000	3	0,816
Spatial Presence: Self-Location	3,563	5	1,413	4,357	5	0,842	3,857	3	0,900
Spatial Presence: Possible Actions	2,938	3	1,436	3,857	5	1,099	3,571	3	1,134
Higher Cognitive Involvement	3,188	5	1,515	3,286	4	1,383	3,571	5	1,272
Suspension of Disbelief	2,625	1	1,360	3,000	1	1,519	2,429	1	1,272

GUESS tests take the longest part of the survey and are using Likert Scale. The test uses a 7-point, unipolar scale. To evaluate results by average, numerical values assigned to each response. 1 indicates “strongly disagree” while 7 stands for “strongly agree”. Test

group is based on Turkish individuals. Therefore, Turkish translations of the GUESS Survey have been used.

Table 4.2: GUESS results

	Boccia			Handcycle			Sledge Hockey		
	Avg	Mode	Std. Dev	Avg	Mode	Std. Dev	Avg	Mode	Std. Dev
I think it is easy to learn how to play the game	5,692	6	1,316	6,154	7	1,676	5,000	5	1,414
I enjoy playing the game	4,929	5	1,817	6,000	7	1,528	5,500	6	0,837
I think the information provided in the game (e.g., onscreen messages, help) is clear	5,643	6	1,393	6,077	7	0,954	5,500	6	0,837
I always know my next goal when I finish an event in the game	5,385	6	1,758	5,750	7	1,545	5,667	6	0,516
I think the game is fun	5,308	7	2,016	5,923	7	1,754	5,833	6	0,753
I always know how to achieve my goals/objectives in the game	4,714	5	1,773	5,167	4	1,749	5,833	7	1,169
I find the controls of the game to be straightforward	5,231	6	1,589	5,615	7	1,850	4,833	6	1,602

I feel very confident while playing the game	4,846	4	1,625	5,636	7	1,859	4,667	6	1,966
I am likely to recommend this game to others	5,462	6	1,613	5,833	7	1,749	6,167	6	0,408
I feel the game provides me the necessary information to accomplish a goal within the game	5,077	5	1,754	5,545	7	1,916	5,333	6	0,816
I feel bored while playing the game	3,667	6	2,270	2,909	1	1,921	3,833	3	1,722
I feel the game trains me well in all of the controls	4,615	6	1,981	5,636	7	1,433	5,333	6	1,211
I find the game's menus to be user friendly	5,385	6	1,758	4,909	6	1,814	5,333	6	1,033
I find the game's interface to be easy to navigate	5,167	6	1,467	5,455	7	1,968	5,333	6	1,211

4.2 TECHNOLOGICAL PROBLEMS AND REGULATIONS

During events, there are some technical difficulties with the mobile VR devices and about the target audience, which affected play sessions, surveying and publishing parts dramatically. This section explains those issues to be aware of during further studies.

First issue is the longer recharge rate as Oculus Go Hardware Specifications shows that the battery withstands around 2 hours of gaming from around 3 hours charge, and

affected directly from the battery life (Fitzsimmons & Lynch, 2020). During play sessions, games are played through three devices. Longer recharge rates cause interruptions and idle times.

Another issue of working with Oculus Go is the heating problem. The device lacks a cooling system, and on heavy graphical processes, the device becomes too hot to use after approximately 20 minutes. During the overheat, the device shuts down after a warning, and it needs to be cooled down to open again. Games are specifically developed with low polygon models and lack of post-process; it improves heat time besides FPS. However, device overheating problems could not be prevented during the playtest sessions. As the warning appears, the session is halted for about 15 minutes. This also adds up to the battery recharge times.

As much as the games are designed for inclusive criteria, Mobile VR Devices are not designed for this occasion. They have to be mounted to the head with straps, adjusted accordingly, and both HMD and controller must be changed regularly. Therefore disabled individuals require help in order to play games. Inclusive surveying for Cerebral Palsy, Down's Syndrome, Mental retardation and many others recommended having surveillance (ASPE, 2017). During this study, the test group is formed out of individuals with all kinds of disabilities besides those with no disabilities. In most cases, it is required to be called for a screener. On the other hand, budget and labour limitations make it harder to screen all individuals while filling out the surveys. ASPE also states that some of the individuals who have severe mental retardation have to be excluded from surveys. This also helps to increase accuracy of surveys. On the other hand, chosen surveys are formed from large amounts of questions which leads them to suffer survey fatigue (Porter et al., 2004). Accuracy can be reduced for latter questions with the survey fatigue.

The aim of this project was also to reach as many participants as possible to test iterations. To increase reliability, it requires more individuals from disabled communities. Unfortunately, based on growing case notification rates at Chinese and

international locations, after 30 January 2020, the WHO Emergency Committee declared Covid-19 as an epidemic (Velavan & Meyer, 2020). It dramatically hinders the possibility of playtesting and survey sessions due to global lockdowns.

Oculus Store is an application hub where developers publish their experiences while the users can reach them through the store. To publish games, they expect the game to meet specific requirements and a very strict policy for those requirements. Those requirements can be viewed from their developer sites (Oculus, n.d.). The first part of the requirements' check has a more straightforward process. The second part is rather harder since it requires a human tester to test it and has 3 phases. The "Submitted" phase begins when an app has been received by Oculus. In one hour, the developer may cancel this project and update their applications. Then it turns to the "Under Review" phase. This process can take either one day or more than a week or more, and it is unavailable to make changes on the submitted build until the Changes Requested or Published Phase. It is common to receive change requests. Those requests can vary from FPS improvement to the removal of a library file. After the changes are made, developers need to submit their app and wait for the whole process from the start, which is also time-consuming. After February 2020, store test durations increased dramatically due to the Covid-19 outbreak.

As the development started in 2018, it targets the mobile VR device, specifically Oculus Go. Therefore the test device is arranged as Go too. However, Oculus announced that developers are unable to publish new Go apps or any updates to the Oculus Store after December 18, 2020. After passing the requirements, they gave activation keys. Those keys are supposed to be transferred manually from developers to their users (Oculus, 2020). This unexpected issue made publishing on the store page impossible. Reachability is one of the aims of this study that is damaged dramatically. Created keys are published on the VR4Inclusion website. Players can get their key and download games from Oculus Store by entering them.

5. DISCUSSION AND CONCLUSION

This study provides a field report of developing Virtual Reality games that specifically targets disableds. The motivation behind this was the lack of games and potential in the Virtual Reality Platform. VR4Inclusion adds 6 reachable and inclusive VR sports games to the market. Recent developments in the game industry are taking serious steps towards inclusive games. With more academic and industrial works, inclusive design is getting closer to being mainstream. This also leads to a mutual win situation since disableds are potential customers that have been ignored for a long time.

Table 3.2 shows personal scores during the tournament game of the first dissemination event. The teams formed equally of disabled and non disabled players. High score and low score amount in each team differs. This hints that there is no correlation between team players and their disability and can be played competitively without any disability disadvantage. This is one of the expected and achieved outcomes from the games. Paraplegic games are designed with a focus on player accessibility and mimicking them by reducing the required controller inputs is the major reason for this outcome.

By the results of the GUESS Survey in Table 4.2, Handcycle performs better amongst the three games for the players. Being simple and easy to learn rather than playing by the rules, supporting Usability/Playability factors. From the enjoyment factor, this game also shows better results with the feeling of speed. There can be a direct relation with the primitive joy of the movement as we can see in swings and rollercoasters. Complexity of gameplay is affecting the game experience dramatically for this study. Sledge-Hockey has both mechanics from Boccia and Hand-cycling. It has the lowest preferability than indicated by the numbers of participants in Table 4.1.

As described in the Development and Implementation section, games have been made by simulating 6DoF movement by using 3DoF hand movement input. This method is implemented due to hardware limitations. However there are upgraded mobile VR

devices which support 6DoF controllers. Oculus Quest can be taken as the next iteration of this project's device, Oculus Go. To improve this work, making a comparison between 3DoF Simulation and direct 6DoF input can be researched with test groups. Analyzing the player scores in the same game should show the performance of this approach.

Player Accessibility should not be designed after the core design process, it should be mandatory and integrated into the whole process from the beginning. Most of the games already implemented such features for color blinds and left handedness. This approach helps to increase the balance of competition which may lead to a more enjoyable player experience. Custom input section also supports this accessibility. Some individuals prefer to customize their controllers and keyboard layouts to control the game comfortably while others may require custom controllers for specific disabilities.

Accessibility can also be achieved by customized controllers. Since different disabilities affect individuals with various effects such as lack of grip, some of the fingers unusable or amputated etc. Therefore those motion controllers should be personalised for individuals to improve accessibility. The aim is to create customised controllers for gamers who cannot always approach gaming in the same way, primarily because of limited mobility. It also enables people to play and compete on a level that otherwise was not possible. As there are not many manufacturers for this issue, Able Gamers Charity makes personalised controllers for disabled individuals (AbleGamers 2021). They also support free resources designed to make the world of video gaming a more accessible space on AccessibleGames (AccessibleGames 2019).

During dissemination events, people who have blindness discussed their experience in the Boccia game. They explained how they could see the balls and play the game since all colours are distinguishable and easy to recognise. They also stated their feedback as using more distinguishable colours in the menu and using clean and big icons make games more accessible for them. By the direction of this feedback, increasing VR Game Accessibility for individuals with a certain degree of blindness can be studied.

Most of the players wanted to play games with multiplayer options. Since VR Head-Mounted Displays can be bound to one player, it requires the game to run through a network which requires different discipline and more time to develop. Due to budget and time limitations, games have simplified AI opponents and do not have any multiplayer option. With more time and budget, multiplayer games can be designed and developed on VR Devices. This may also prevent the social isolation that has been mentioned and motivates disabled individuals to participate in social activities with others.

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APPENDICES